Experimental Study on Lateral Bearing Capacity of Brick Walls with R. C. Flange Columns and Ring Beams

Zhang Wang-xi*1, Huang You-hua2, Zheng Ka-yun3, Shi Chu-xian4

Civil Engineering College, Hunan University

1Lu-shan-nan Road, Changsha city, Hunan province, China

*1wxizhang2000@hnu.edu.cn; 2hyhwk@sina.com; 3zhengkayun@126.com; 4shichuxian@sina.com

Abstract

By the lateral bearing capacity tests on 9 composite wall specimens, made of bricks R.C. flange columns and ring beams, with different height to width ratio (*H*/*B*) and under different vertical pressure (σ_0), the effects of the vertical pressure and the overall height to width ratio on the lateral bearing capacity of brick walls were studied, and the failure characteristics and deformation behavior of such walls have been analyzed. By means of experiment and analysis, some significance conclusions were drawn. It is obvious that using R.C. flange column and ring beam is an effective way to improve lateral bearing capacity, especially flexural capacity, and it is strongly suggested to be used when the width of wall between windows is narrow.

Keywords

Brick Wall; Lateral Bearing Capacity; Experimental Study; Flange; Ring Beam

Introduction

With the development demand of building construction, the opening dimension of wall is enlarged while the wall between windows is diminished. In order to satisfied the demand of earthquake fortification, the narrowed wall between windows is constructed of concrete, forming a composite wall specimen, which is made of bricks, R.C. flange columns and ring beams. Domestic and foreign researches on flexural strength and shear strength of the wall with constraint components are mature. However, the flexural capacity and the overall flexural capacity of building, especially the flexural capacity and shear capacity of the composite wall with R.C. flange need further exploration. The flexural capacity and shear capacity can be called a common name--lateral bearing capacity, for they can be hardly to tell apart in the same wall. Experimental results have revealed that the main factors affecting the lateral capacity are overall ratio of height to width of wall (*H*/*B*), vertical pressure (σ_0), distribution and ratio of vertical reinforcement, distribution and ratio of horizontal reinforcement, ratio of concrete area, mechanical property of masonry material (such as brick, mortar, concrete and reinforcement) and so on. By the lateral bearing capacity tests, the effects of the vertical pressure (σ_0) and the overall height to width ratio (*H*/*B*) on the lateral bearing capacity of brick walls were studied, and the failure characteristics and deformation behavior of such walls have been analyzed.

Lateral Test and Analysis of Composite Wall

Design and Fabrication of Wall Specimens

All the wall specimens are divided into three groups. The specific numbers and structural parameters are showed in FIG. 1 and the detailed dimension is showed in TABLE 1. There is only dovetail joint between concrete flange column and brick masonry, but no horizontal tie bars. The brick wall is laid cross bond before concrete is placed by two average workers, and the method of assembly line is adopted. In terms of the Chinese code for construction and acceptance of masonry structure engineering (GB50203-2002 or GB50203-2011), all specimens are two-sided pointed，as well as the choice of thickness of mortar joint and wet degree of red brick. The standard test blocks of each dish of mortar and concrete are collected in accordance with the applicable codes or standards.

Wall Specimen Test Arrangement

As the wall specimen test arrangement showed in FIG. 1, taking the single point loaded specimens as reference groups, the lateral inverted triangular

loaded is realized by distribution beam (two point - loaded), specially, the weight of device is not included in vertical pressure (σ_0).

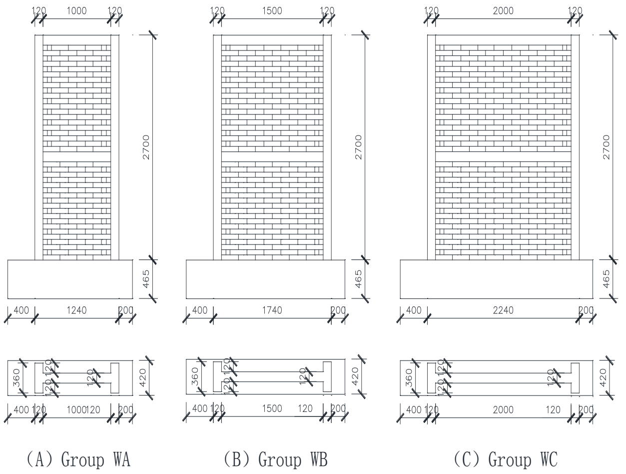


FIG. 1 WALL SPECIMEN DIMENSIONED DRAWING

Data Acquisition Methods

In order to obtain or to collect the responsing data of the wall specimen, some measuring devices are introduced, in which pressure transducer is used to measure the lateral loads. 3×5 mm resistance strain gage is adopted for the strain of the steel bars in the concrete columns. The lateral displacement can get by displacement meter and the section strain of the bottom of the masonry is obtained with the help of dial gauge. Synchronous hydraulic pressure equipment, control the vertical pressure; while 5×150 mm resistance strain gage, measures the concrete strain of the columns.

Loading Program and Experimental Procedure

Firstly, the vertical load to the set point by three steps is added, and then the lateral load is raised which is controlled by the value of load before incipient crack, taking 1/5 ultimate load for each level, in other words, each level is about 50 kN more than the former one. After the incipient crack, the lateral load is controlled by the incipient crack displacement of the top wall Δ_c and each level of the lateral displacement is 1~2 mm more than the former one, until the wall has been damaged badly.

Experimental Facilities and Devices

This experiment was completed in the Chinese Education Ministry Key Laboratory for Civil Construction Safety & Energy-saving Monitoring of Hunan University, and the experimental facilities is showed in FIG. 2. The lateral load is transferred to the wall by distribution beam. With the application point that oil jack do to the distribution beam, dividing the distance from top to bottom distribution point (top beam to bottom beam) into 1:2, inverted triangular loaded is realized. As showed in FIG. 2, the loaded point of the reference specimen is on the top application point, axis of the top beam.

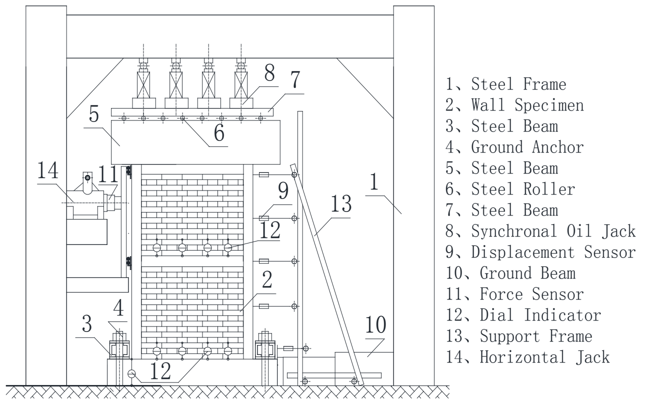


FIG. 2 EXPERIMENTAL FACILITY OF WALL SPECIMEN

Experimental Results

Material Performance

By testing double sheared test specimen, the average shearing strength is 0.42 MPa, with the coefficient of variation is 0.154. The reinforcement（Φ10, Chiese Code）yield strength, tensile strength and average of elongation are 294.3 MPa, 428.3 MPa and 28.15% respectively, with coefficient of variation 0.069, 0.030 and 0.057. The concerete mean value of the cubic compressive strength is showed in TABLE 1. The average compressive strength of single brick is 12.6 MPa, with coefficient of variation 0.191. The mortar average compressive strength and coefficient of variation are 13.1 MPa and 0.364 respectively.

Lateral Resistant Performance

Experimental results of lateral resistant performance is showed in TABLE 2.

Failure Process of Specimen

Each specimen has basically experienced three stages from loading to failure, flexibility, elastoplastic and failure phase. (1) Flexibility phase: the stress–strain relationship of each specimen's masonry bottom section, concrete column reinforcement and concrete are substantially linear elastic before incipient crack and the composite wall display obviously elastic deformation characteristics. (2) Elastoplastic phase: after incipient crack, the first diagonal crack emerges

in the center sill and soon extends. The second, third, etc. crack turns out in the bottom of the brick w all with increasing load, meanwhile, diagonal cracks emergeon the coping. Each crack develops in certain direction, and extends to the concrete column and concrete beam. Also, new cracks turn out in the brick masonry. (3) Failure phase: with the load exceeding the ultimate load, the lateral displacement of the specimens develops quickly. With the continuous loading to collapse load, the bearing capacity of the wall declines drastically, making the brick wall local crisp and begin to fall in large area. For the safety reason and the appearance of characteristics of damage, the experiment is stopped. In the failure phase, no visible cracks and separation phenomenon arise between concrete column and brick masonry. The final crack distribution for each specimen is showed in FIG. 3.

TABLE 1 SPECIMEN NUMBERING AND STRUCTURAL PARAMETERS

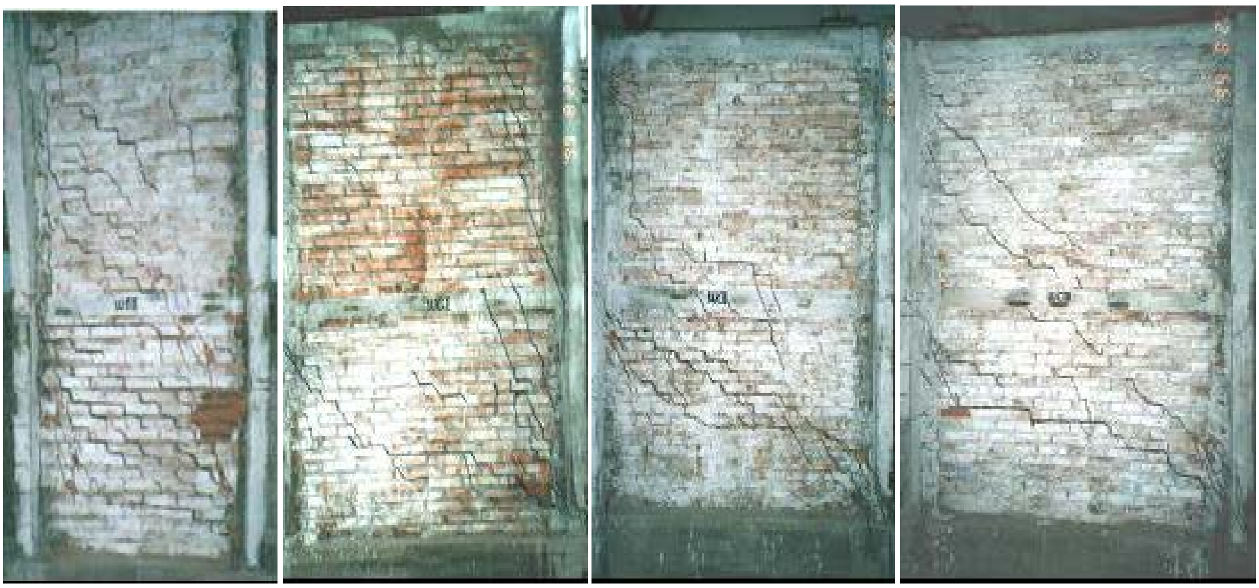
Specimen Number	**Height-width ratio(H/B)**	**Longitudinal reinforcement of concrete flange columns**	**Longitudinal reinforcement of ring beams**	**Hooping reinforcement of columns and beams**	**Vertical pressure /MPa**	**Number of loaded point**
WAI	2.25	8Φ10	4Φ10	Φ8@200	0.6	2
WAII	2.25	8Φ10	4Φ10	Φ8@200	1.0	2
WAIII	2.25	8Φ10	4Φ10	Φ8@200	1.0	1
WBI	1.55	8Φ10	4Φ10	Φ8@200	0.6	2
WBII	1.55	8Φ10	4Φ10	Φ8@200	1.0	2
WBIII	1.55	8Φ10	4Φ10	Φ8@200	1.0	1
WCI	1.21	8Φ10	4Φ10	Φ8@200	0.6	2
WCII	1.21	8Φ10	4Φ10	Φ8@200	1.0	2
WCIII	1.21	8Φ10	4Φ10	Φ8@200	1.4	2

TABLE 2 EXPERIMENTAL PARAMETERS AND RESULTS OF THE COMPOSITE WALLS' LATERAL BEARING CAPACITY

Number	WAI	WAII	WAIII	WBI	WBII	WBIII	WCI	WCII	WCIII
Cubic concrete compressive strength, f_{cu}/MPa	12.2	12.2	16.1	16.1	15.1	15.1	17.5	17.5	12.4
Incipient crack lateral load, P_c/kN	57.4	81.0	71.3	145.0	96.7	63.4	169.2	242.9	148.6
Incipient crack lateral displacement of top wall, Δ_c/mm	8.29	1.80	2.06	1.63	4.19	2.92	1.06	2.42	1.29
Ultimate lateral load, P_u/kN	152.9	201.2	159.5	215.1	204.8	178.2	250.2	316.6	329.3
Ultimate displacement of top wall, Δ_u/mm	59.5	27.4	41.60	29.67	46.22	40.37	10.50	12.29	8.61
P_u/P_c	2.66	2.48	2.24	1.48	2.12	2.81	1.48	1.30	2.22
Δ_u/Δ_c	7.18	15.22	20.19	18.20	11.03	13.83	9.91	5.08	6.67

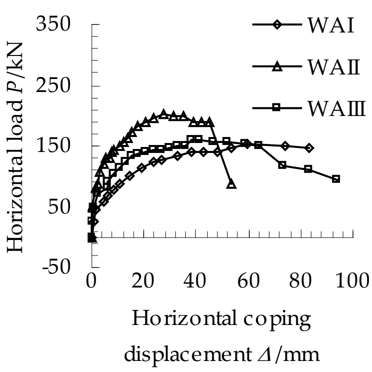
NOTE: P_c and Δ_c respectively refers to the previous lateral load and the coping displacement when first observed the macroscopic crack of the composite wall. P_u and Δ_u refer to the lateral load and lateral coping displacement of the peak point in the load P-displacement Δ curve.

WAI WAII WAIII WBI WBII

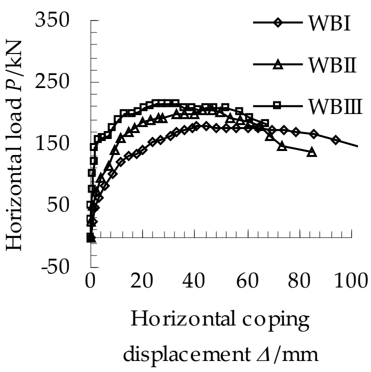


WBIII WC Ⅰ WC Ⅱ WCIII

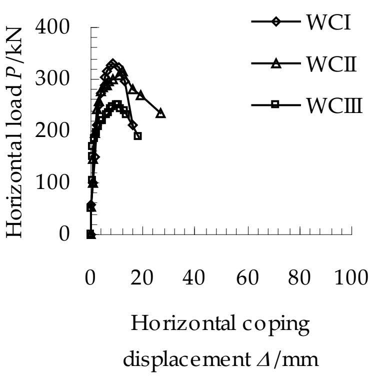
FIG. 3 CRACK DISTRIBUTION PHOTOS



WAI, WAⅡ, WAⅢ P-Δ curve



WBI, WBⅡ, WBⅢ P-Δ curve



WCI, WCⅡ, WCⅢ P-Δ curve

FIG. 4 LATERAL HORIZONTAL LOAD P - HORIZONTAL COPING DISPLACEMETN Δ CURVE

Load-Displacement Relationship Curve

All the nine wall specimens' lateral horizontal load *P*-horizontal coping displacement Δ curve is showed in FIG. 4, in which *P* is the load that measured by the pressure transducer of oil jack and Δ is the pure value of lateral displacement measured by displacement meter, deducting the bottom wall displacement and rotary displacement.

Analysis and Discussion

Vertical Pressure Ration Effect on Incipient Crack Load and Ultimate Load

FIG. 5 shows that incipient crack load P_c and ultimate load P_u vary with vertical pressure ratio(σ_0/f), in other words, σ_0/f comparative significantly affects Pc and Pu. As to the group of WC (WCI,WCII,WCIII) specimens, ultimate load increases with σ_0/f, but the tendency decreases. Whereas the incipient crack load increases at first then decreases. From the relationship of WA, WB specimens' incipient crack load and ultimate load with σ_0/f, it can be deduced that the incipient crack load and ultimate load relate with not only σ_0/f, but also the overall height to width ratio (*H*/*B*).

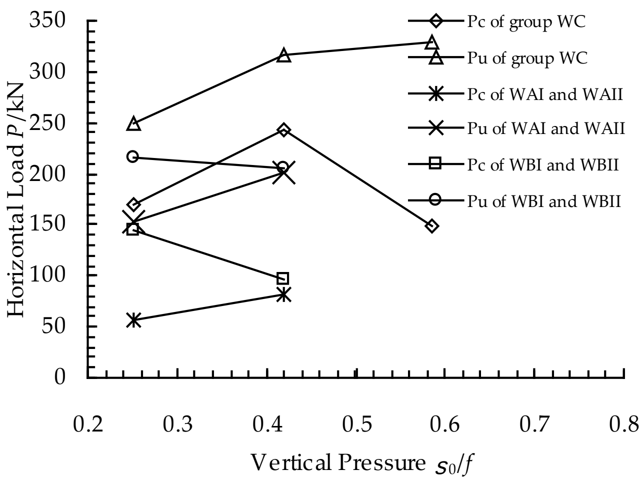


FIG. 5 EFFECT OF σ_0 TO *P*c AND *P*u

Influence of H/B on Incipient Crack and Ultimate Load

As shown in FIG. 6, both of the incipient crack load and ultimate load increase, when the vertical pressure loading on group of WAI, WBI, WCI is 0.6 MPa and on group of WAII, WBI, WCI is 1.0 MPa, with *H*/*B* of each group varying from 2.25, 1.55 to 1.21.

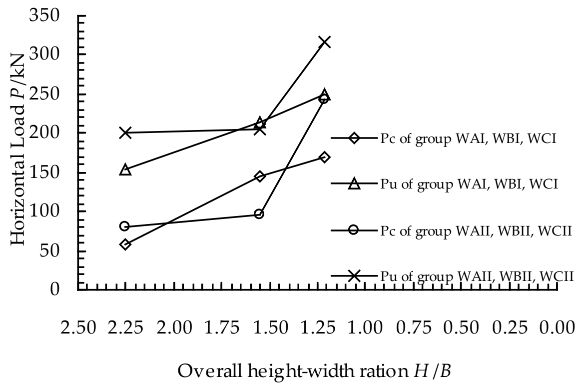


FIG. 6 INFLUENCE OF *H*/*B* ON *P*c AND *P*u

Influenceof Loading Method on Ductility, Incipient Crack and Ultimate Load

According to the number of the loading point on each of the tested wall specimen, there are two types of loading method in the experiment. WAII and WBII are two point loaded (inverted triangle loaded), while WAIII and WBIII are single point loaded. It can be seen in FIG. 7 that the incipient crack load P_c and ultimate load P_u are reduced with the two point loaded (by distribution beam) altered to single point.

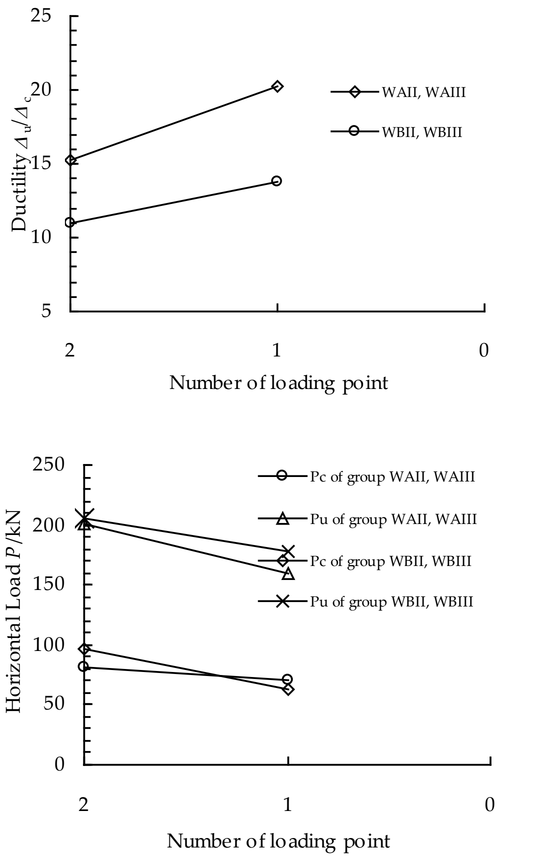


FIG. 7 INFLUENCE OF LOAD METHOD OT DUCILITY, INCIPIENT CRACK LOAD AND ULTIMATE LOAD

Conclusions

By means of experiment and analysis, the following conclusions can be drawn.

Under the in-plane lateral load, the collaborated performance of the brick specimens with R.C. flange columns and ring beams, is favorable and there is no obvious separation among the R.C. flange column, ring beam and brick wall.

From loading to destruction, specimens basically experience three stages: elasticity, elastic-plastic and failure stage. In the loading procedure, the initial diagonal crack emerges at the bottom of the brick wall, and extends quickly. With bearing load up, new diagonal cracks keep cropping up between coping and wall. When the horizontal load approaches to the failure load, the bearing capacity of the wall declines drastically, with coping and bottom wall locally pressed crisp and large area to fall off.

In the wake of rising of the vertical pressure, the ultimate load of the composite wall is increasing, however, the tendency is slow. The influence of the vertical pressure on the incipient crack is less evident.

In the condition of constant width of wall specimens with overall height-width ratio decreased, the incipient crack load and ultimate load rise.

The loading mode significant impacts the incipient crack load and ultimate load and after the two-point load mode has changed to single-point, in addition, both the incipient crack load and ultimate load are reduced.

According to the traditional definition of wall ductility(Δ_u / Δ_c), all the specimens' ductility is large, in which the WAIII reaches 20.19. Therefore, as to the composite brick wall specimens with R.C. flange columns and ring beams, it is suggested to quote the ductility definition of R.C. structure, that is, the ratio of ultimate displacement and displacement when reinforcement yields.

Using R.C. flange column and ring beam is an effective way to improve lateral bearing capacity, especially flexural capacity, and it is suggested to be used when the width of wall between windows is narrow.

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Zhang Wang-xi was born in Huanggang, Hubei Province, China in 1971. He is associate professor in the field of Structural engineering in the Civil Engineering College of Hunan University. He is author of two books and more than 30 research papers in the field of experiment or FEM analysis of Structural Engineering, Engineering Mechanics, or Soil Engieering. Currently, he is the Deputy Director of Department of Structure Engineering, and member of the Chinese Education Ministry Key Laboratory for Civil Construction Safety & Energy-saving Monitoring of Hunan University , Chinese Civil Engineering Society, Chinese Masonry Structure Society, and Concrete Structure Society.

Huang You-hua was born in Xiangxiang, Hunan Province, China in 1963. She is associate professor in the field of Structural engineering in the Civil Engineering College of Hunan University. She is author of two books and more than 20 research papers in the field of CAD design or FEM analysis of Structural Engineering, Engineering Mechanics, or Soil Engieering. She is member of Chinese Civil Engineering Society, Chinese Masonry Structure Society, and Concrete Structure Society.

Zheng Ka-yun was born in GuanFeng, Jiangxi Province, China in 1987. She is associate engineer, and postgraduate student in the field of Structural engineering in the Civil Engineering College of Hunan University. She is author of more than 4 research papers in the field of aseismic design or FEM analysis of Structural Engineering, Engineering Mechanics and member of Chinese Civil Engineering Society.